



REMR TECHNICAL NOTE GT-RE-1.2

METHODOLOGY FOR SELECTING SHEAR-STRENGTH PARAMETERS OF ROCK

PURPOSE: To identify and describe a methodology for use by the Corps of Engineers in the selection of shear strength parameters for rock.

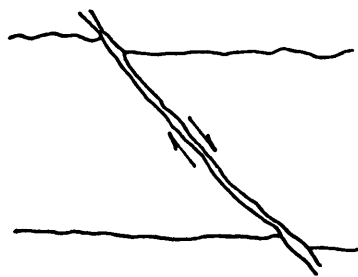
APPLICATION: Selection of appropriate shear strength parameters is essential to a meaningful analysis in assessing the sliding stability of rock slopes and of gravity structures founded on rock.

ADVANTAGES: Procedures are available to precisely estimate prototype shear-strength parameters for rock masses. However, such procedures can be expensive and are often unnecessary. The methodology described in this Technical Note emphasizes processes for selecting shear strength parameters appropriate for a particular assessment need.

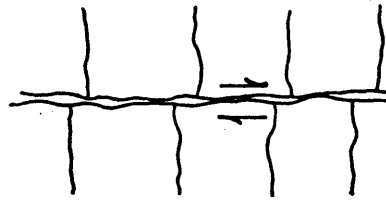
BACKGROUND: Shear failure of a rock mass is a complex phenomenon. Modes of potential failure can vary from failure through intact rock, to failure along a single discontinuity, to failure along a series of discontinuities, to general rock mass failure where failure occurs both along discontinuities and intact blocks of rock as illustrated in Figure 1. Small laboratory shear tests which attempt to model prototype loading conditions seldom provide true measurements of in-situ shear strength. The reason for this deficiency is the dependency of shear strength on the size of rock test specimens. In general, accuracy of measured shear strengths determined from shear tests increases with increasing specimen size. However, large-scale shear tests are expensive and therefore are reserved for critically located weak seams. Fortunately, the geotechnical engineer has at his disposal a variety of relatively inexpensive alternative approaches from which to select appropriate prototype shear strengths. The alternative approach concept emphasizes a process of exercising sound judgment rather than precise measurement. Thus, shear strength parameters obtained by the alternative approach are "selected" rather than "measured."

PREREQUISITES: Selection of meaningful shear strength parameters for use in assessing sliding stability requires, at least, a fundamental appreciation of basic failure mechanisms associated with each of four definable modes of potential failure in rock. The four potential modes of failure include: within intact rock; along a clean single discontinuity; along a filled single discontinuity, and within the general rock mass. In addition, knowledge of and input from six essential processes are required. These basic and necessary processes are summarized below. All must be considered in detail before shear strength values are selected.

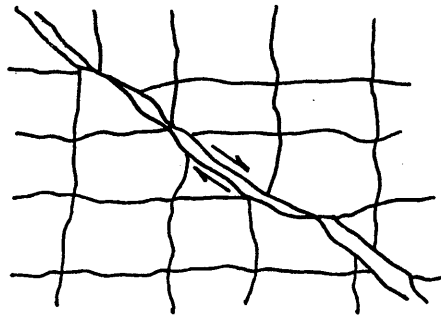
- a. Exploration. The exploration program defines all potential failure surfaces and the geometry of these surfaces. The exploration



a. Intact rock failure.



b. Failure along a single discontinuity.



c. General rock mass failure.

Figure 1. Modes of potential failure.

program provides information concerning potential failure modes (such as intact rock or clean single discontinuity) that control stability as well as the kinematics; i.e., is a failure along that surface kinematically possible and if failure is possible is it a two- or three-dimensional surface within the rock mass? Detailed knowledge of the exploration program is necessary; both in terms of what was found, and in terms of what might have been missed.

- b. Sampling. Shear strengths are often selected based on appropriate interpretation of small-scale upper- and lower-bound shear tests. Such tests require high-quality, least-disturbed "undisturbed" samples. Knowledge of the kinds of possible sample disturbance and their effects on measured strength results is required.
- c. Loading conditions. Loads include all loads acting on the structure and loads generated by the mass of the structure and/or material above the potential failure surface under consideration as well as unit area pore-water pressures acting within the material defining the potential failure surface. Loading conditions define stress ranges over which to extrapolate shear strength parameters-- a vital consideration for the use of curvilinear failure criteria which are typical of most criteria used for rock. Also, pore-water

pressure considerations are often necessary for establishing test specimen drainage conditions; i.e., drained or undrained tests.

- d. Stress-strain characteristics. The laboratory-obtained stress-strain curve is often an important indicator of the deformation behavior which may lead to failure in the field. Considerations of strain compatibility are particularly important when selecting strengths for cases where the potential failure surface comprises two or more materials of different stress-strain response characteristics. For example, consider the hypothetical hydraulic gravity structure shown in Figure 2a where the critical potential mode of failure was found to be along a path denoted by points A B C. From Figure 2b it can be seen that the stress-strain responses of the two materials along the potential plane are different. If the peak strength of material B is used in design, then material A cannot be relied upon to develop its peak strength, since the magnitude of strain is not sufficient. On the other hand, if the design is based on the peak strength of material A, material B would already be at or close to its residual value.

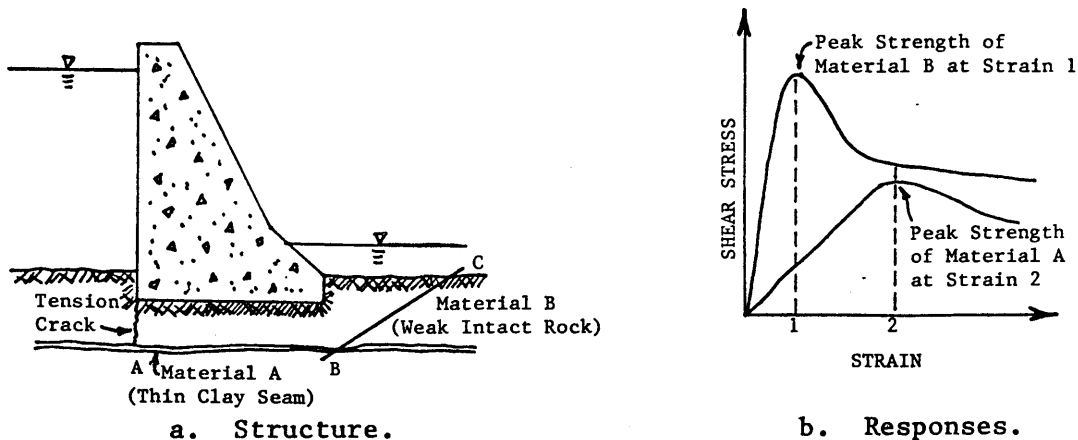


Figure 2. Hypothetical gravity structure and hypothetical stress-strain responses for foundation-materials A and B with constant normal stress.

- e. Available shear tests. A fundamental appreciation of the various types of shear tests available, their limitations, and their applicability is necessary in order to choose the test which is best suited for the failure mode under consideration. A Waterways Experiment Station report (Technical Report GL-83-14, "In Situ and Laboratory Shear Devices for Rock: A Comparison") provides guidance in this area.
- f. Definitions of failure. Shear-strength parameters selected for assessing stability are interpreted directly from a single or a range of possible failure envelopes chosen to define the upper limit of allowable shear strength. The envelopes may be developed from a series of shear tests over the range of stress conditions of interest, or a range of pore-pressure conditions, or by specimen

size, or by other approaches. Because of associated scale effects failure envelopes chosen for strength selection seldom define actual upper limits of prototype strength. Whether a given failure envelope predicts prototype strengths that are too high or too low is dependent on the appropriate choice of the limits of shear stress or strain used to define failure for each tested condition.

Shear-Strength Selection: The geotechnical engineer has at his disposal at least three approaches upon which to base selection of shear-strength parameters. The three approaches can be summarized as: use of values obtained from limited-scale test results; use of rational values based on evaluation of geological conditions and rock mechanics characterization; and use of shear strengths derived from empirical failure criteria. The choice of approach relies on judgment tempered with a thorough understanding of the preselection processes discussed above. Regardless of the approach chosen, the engineer must have a feel for the degree of precision required for the selected strengths. The degree of precision required is controlled by the hypothesized failure mode, number and types of assumptions necessary, random uncertainty, and the method of stability analysis. In this respect, it is often necessary to conduct a sensitivity analysis prior to the selection process. Such an analysis will provide a range of shear strength parameter values necessary to ensure stability.

To thoroughly describe the advantages, disadvantages, and limitations of each approach requires considerable attention to detail which is beyond the intent of this Technical Note. Thus, each approach will only be briefly discussed herein. For details of application, refer to items in the Selected Bibliography.

- a. Shear tests. As a general rule, shear strengths based on the peak values of shear stress for small intact samples or small samples containing the natural discontinuity (NX to 6-in. diameter) will overpredict prototype rock strength. Such tests are useful in establishing the upper limits of strength. With proper care in specifying the definition of failure and/or specimen preparation, lower limits of strength can also be obtained. For example, lower-bound strengths for discontinuous rock might be obtained from shear tests on smooth sawn specimens. Tests to establish the upper and lower limits of strengths for a potential mode of failure quantify the bounds of all likely prototype strengths. If a sensitivity analysis indicates that lower-bound strengths will not ensure stability, then rational techniques must be employed to justify upward adjustments of lower-bound strengths. In no case should upward adjustments exceed the established upper limits of strength.
- b. Rational approach. Deere (1976) was perhaps the first to propose the rational approach as a legitimate means of quantifying shear strength. As proposed, the approach was intended for single clean discontinuities, but it may be extended to other modes of failure. The approach relies heavily on engineering judgment and experience.

Shear-strength values, proven by satisfactory performance at existing sites with both geological conditions and rock-mechanics

characterization similar to a site under consideration, can be judged as representative of the new site. Back-calculations to determine operative parameter values in failed slopes of comparable geology offer a useful method of quantifying strengths for the selection process. Strength selection based on experience should be compared with upper- and lower-bound strengths obtained from shear tests.

As initially proposed, the approach referred to the rational adjustment of lower-bound strengths to account for the surface roughness of asperities on clean discontinuities. In that context, the effective asperity angle was added to the basic friction angle of the rock material. The effective asperity angle was obtained from visual observations or physical measurement of joint outcrops as well as experience.

- c. Empirical approach. In recent years, a number of empirical failure criteria have been proposed which offer a means of addressing scale effects. Empirical approaches are available for intact rock, clean discontinuities, and general rock-mass modes of failure. The set of approaches offers an attractive alternative to expensive, large-scale, in-situ tests. But, because the approaches have not yet withstood the test of time, judgment should be exercised in their use.

In selecting shear-strength parameters for rock, the engineer should not be limited to a single approach, but rather should incorporate several approaches into the selection process. Specifically, total reliance on shear test data alone divorces the selection of strength values from both the reality of largely undescribed rock masses and from prior operational experience. Comparison of values obtained from several alternative approaches, together with a thorough understanding of rock-mechanics principles and prerequisites, will provide the necessary basis for selection of meaningful shear-strength parameters. A warning basic to all engineering is to judge soundly rather than measure precisely.

SELECTED BIBLIOGRAPHY:

a. General:

1. Goodman, R. E. 1976. Methods of geological engineering in discontinuous rock. West Publishing Company, New York.
2. Hoek, E. and Bray, J. W. 1981. Rock slope engineering, 3rd ed., The Institution of Mining and Metallurgy, London.
3. Nicholson, G. A. 1983. Design of gravity dams on rock foundations: sliding stability assessment by limit-equilibrium and selection of shear strength parameters. US Army Engineer Waterways Experiment Station, Vicksburg, MS. Technical Report GL-83-13.

- b. Rational approach: Deere, D. U. 1976. Dams on rock foundations--some design questions. In: Rock engineering for foundations and slopes, proceeding, specialty conference, American Society of Civil Engineers, Geotechnical Engineering Division, Vol 2, pp 55-85.
- c. Empirical approach:
 - 1. Barton, N. and Choubey, V. 1977. The shear strength of rock joints in theory and practice. In: Journal, Rock Mechanics The International Society for Rock Mechanics, Vol 10, No. 1-2, pp 1-54.
 - 2. Hoek, E. and Brown, E. T. 1980. Empirical strength criterion for rock masses. In: Journal of the Geotechnical Engineering Division, American Society of Civil Engineers, Vol 106, No. GT9, pp 1013-1035.
 - 3. Ladanyi, B. and Archambault, G. 1939. Simulation of shear behavior of a jointed rock mass. In: Proceedings, eleventh symposium on rock mechanics, Society of Mining Engineers, pp 105-125.
 - 4. Patton, F. D. 1966. Multiple modes of shear failure in rock and related materials. Ph.D. thesis, University of Illinois, Urbana, IL.